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Publication date:
1989

Document Version
Accepted author manuscript, peer reviewed version

Link to publication from Aalborg University

Citation for published version (APA):
Larsen, T. (1989). *Practice and Problems in Denmark*. Paper presented at Expert Meeting on Long Sea-Outfalls, Brussels, Belgium.

Expert meeting on long sea-outfalls organized by the Commission of the European Communities on April 13 and 14, 1989 in Brussels

Practice and Problems in Denmark

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1 Scope and background

The scope of this document is to give an overview on the Danish practice for discharging sewage to the sea. It do not contain a formal summary of legislation and design criteria, but the intention of the paper is to explain the development and its background during the last 25 years in which period our practice gradually has arisen.

With basis in the University of Aalborg, Denmark, the author has been involved in research and design of sea outfalls since the beginning of the seventies. It is controversial to give examples of disfunctioning of sea outfalls by name and it has therefore been avoided here and only the general experiences on this point are mentioned.

2 Introduction

About 60% of all sewage in Denmark is discharged to the sea because nearly al the major cities have grown up around local harbours. Since the longest distance from any point in Denmark to the sea is 55 km, bathing in the sea is much more frequent than bathing in fresh water. Sewage discharge and bathing in the sea are therefore in conflict at a number of locations.

Bathing water problems have been identified the last 40-50 years. Probably for the first time a systematic investigation was carried out in order to describe the expected spread of the sewage field from a planned outfall (not a long sea outfall) was in 1947 in the city Esbjerg. The used technique was the tracing of droques. However, the background for this investigation was bacteriological measurements of the bathing waters which started in the mid thirties.

Long sea outfalls with diffusors was introduced in the sixties and the earliest were in function around 1970. Nowadays almost all sewer plants in coastal cities have long sea outfalls which was designed according to the bathing water considerations.

Only treated sewage is discharged to the sea in Denmark.

3 Legislation — a brief overview

The discharge of sewage to external waters is basicly controlled by the environmental protection act, after which the local country council lay down the conditions and gives the "discharge permission". Denmark, with its 5 million inhabitants, has three administrative levels; government, county, and municipal; the country is split into 13 counties and around 350 municipalities.

The sewage plants and the sea outfalls are owned by the municipalities or in a few cases by private companies. The "discharge permission" and the monitoring of the impact on the environment of the sea outfall is in principle the responsibility of the county council (although the "discharge permission" often contents details about what controle of the discharge itself the owner of the plant and outfall shall carry out).

It should be mentioned here that the technical staffs in the counties includes biologists, engineers, and technicians specially trained for solving the above mentioned tasks.

According to the Danish planning acts and the environmental protection act the county council has to lay down a general plan for the external waters, rivers, streams, lakes and the coastal zones with respect to water quality and discharge. This plan defines the water quality in the surroundings of the discharge and gives implicit the restrictions in the "discharge permission" on the quantity and quality of the discharge.

Up to 1987 it was a local (and political) county decision to set the demands on the quality of the discharge based on a set of guidelines from the ministry of environment and on the above mentioned plan for quality of the external waters. But in 1987 the Danish parlament decided through the act of "saving the sea environment" to cut down the overall discharges of nutreants (nitrogen and phosphorus) to 50% of the actual level. This reduction should be obtained by controlling the discharge from the agriculture, the industry, and the municipal sewer plants. The act gives a 5 year period to fulfill its objective.

After the act of "saving the sea environment" followed a governmental notice in which the maximum allowed concentrations of nutreants in all major discharges were layed down. The limits are 8 mg/ℓ for nitrogen and 2 mg/ℓ for phosphorus.

As a consequence of this, an intense extension of Danish sewage plants now takes place. The removal of nutrients in principle require a third treatment stage after the biological or chemical stage for the removal of organic matter. Different variations and combinations of biological and chemical methods are now being implemented. The overall costs in Denmark are estimated to be 15 mia. DKK or 1.2 mia. ECY, which equals approximately 250 ECY per inhabitant in the country.

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It is expected that this plan will give a further improvement of the bathing waters too, but before practical experiences with the new sewer plants have been obtained, it is difficult to say if the improvement can be seen on the bathing water statistics.

4 Danish coastal waters

From an oceanographic point of view the processes in the Danish waters are very complex because of the situation in the transition between the Baltic and the North Sea. The fresh water discharge to Baltic is in the order of magnitude of 10,000 cubic meters per sec. Due to the vertical mixing in the Baltic this fresh water outflow through the Danish belts is increased with a factor 5 to 10 to give a two-layer flow with outgoing brackish surface water and inflowing dense North Sea water. All Danish coastal waters except the west coast of Jutland are strongly influenced by this picture.

The Danish geological background is dominated by glacial deposits which has lead to shallow coastal waters. Most Danish sea outfalls lie on water depths less than 10 m and in general the discharge takes place to the above mentioned surface layer. If we again except for the west coast of Jutland, the salinity in the discharge zone vary from 10 to 25 pro mille. As the tide is low, less than 0.5 m, the currents are weak under stable atmospheric conditions. This makes a complicated unsteady circulation pattern in the near-shore zone, where vertical density gradients often are seen.

The combination of stratisfied waters and a high primary production in the surface layer has given an increasing source of oxygen consuming organic matter sedimenting to the bottom. The consequence is seen as oxygen depletion in the near-bottom layer, especially in the late summer where the temperature is on its highest. Because of the difference in the time scale between the primary production of plantonic algae and the time scale of the plume dilution from outfalls, there is no directly coincidence between the plumes and the primary production.

The Danish fjords and estuaries are significant influenced by nutrients coming from agriculture, sewage discharge, and the atmosphere. The open waters are without doubt influenced too, but it seems to be an open question whether improvements can be expected by the Danish efforts alone.

The non-Danish sources of nutrients are of course the countries around the

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Baltic, but the influence of the north-going "Jutland current" in the North Sea along the west coast of Jutland is studied intensely at present. The major part of the nutrients from the Rhine River is flowing in this current.

5 Placing sea outfalls

Sewage treatment in Denmark is the task of the municipality. This unit is in many cases small (down to 3-4000 inhabitants) and the size of the town restricts the means to establishment and maintenance of the treatment plant and sea outfall. Due to the limited means, examples of most inexpedient placing of sea outfalls can be mentioned. Some of the examples can be found along the west coast of Jutland near the inlets.

The conflict is that construction and finance often stimulate the placing of sea outfalls in the most sensitive receiving water.

Special considerations should be taken in areas with soft and muddy bottom sediments, which are sensitive to both particulate organic matter, heavy metals, and bacteria. It is the author's point of view, and not necessarily an official Danish strategy, that secondary treatment always should be used in cases where particulate organic matter can be expected to accumulate on the sea bottom.

6 Initial dilution

To ensure the achievment of the general demand on avoiding a visible surface plume above the diffusor, it has been an accepted practice to design the diffusor to give a surface dilution, in a way that the density difference between the ambient sea water and the diluted sewage is less than 0.5 kg/m^3. Most often the dilution was calculated from Abram or Cederwall's wellknown formulas for stagnant waters.

Because of the earlier mentioned variations in the salinity, the nominal initial dilution will vary from 25 to 50.

The general experience on this point seems to be good. Probably because the actual dilution most of the time is significant higher due to the influence of the currents. This is the disadvantage with our practice. It would be more appropriate to have a design criteria which prompt the diffusor to be placed

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where the currents are strong. A criterion like

Initial dilution should be more than 30 in stagnant water and more than 50 in at least 90% of the time

or the like, could be a suggestion.

The origin of the Danish practice, which goes back to Professor Harremoës' far-sighted research an development in the 60'ies, was to ensure that the surface plume dilution could take place without being restrained by vertical density gradients. Therefore, it has not been practice to distinguish between different degrees of treatment in relation to initial dilution.

7 Far field dilution, bathing waters

Since the mid sixties most outfalls have been designed to meet bathing water standards. Although the standard used at first were based on Californian practice, the philosophy and substance were very close to the EC bathing water directive. This means in practice that all Danish sea outfalls were planned according to standards which are equal to or stronger than the directive.

It should be understood that most outfalls were established on the background of bad experience with the local bathing water. This means that the surrounding beaches were classified as non-bathing waters in the design stage. Therefore, the design goal has most often been to re-establish bathing water along the beaches.

The practical formulation of the design criterion was then that the length of the sea outfall should ensure the E.coli (faecal coliforme) concentration not to exceed 1000 bacteria per 100 $m\ell$ in more than 5% of the time in the summer period (May to September inclusive) along the 2 m contour.

The practice for the documentation of this well-defined objective in the design stage differs from comprehensive tracer investigations with the support of advanced numerical models, to simple calculations of steady plume dilution for a few assumed design situations.

Despite these variations in the documentation level it is the author's impression that in general the function of the sea outfalls is better than assumed in the design stage in respect to bathing waters.

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8 Far field dilution, industrial discharges

Denmark has only a few industrial sea outfalls. In general the industry have to discharge their sewage to the municipal sewer system. This is of course not without problems, especially for the treatment plants, but on the other hand this keeps the Danish coastal waters almost free of direct industrial discharges. It is worth mentioning that in principle all discharges from the agricultural industry in Denmark nowadays pass through municipally sewer plants.

Among the few directly industrial sea outfalls in Denmark, are some of the most debated environmental problems in the country at all, which makes it difficult to mention the cases by name in this brief presentation. In general the picture is that the discharge began decades ago in a relative small scale without many restrictions. As the plants and discharges grew, the legislation and the public interest simultaneously increased to meeet in some emotional and political conflicts in the end of the seventies and the beginning of the eighties.

Today all directly industrial discharges have restricted permissions both on quantity and concentration.

9 Control and monitoring

The control of the bathing waters takes place according to guidelines from the Danish ministry of environment. The guidelines give the statistical details on the control. In areas where the earlier years showed little or no influence of sewage 10 samples per season is required, but in areas where uncertain bacteria levels are seen 20 samples are needed.

Depending on the location, the bottom sediments, and musselbanks (if any) are regularly monitored for organic matter, bacteria, and heavy metals.

The municipal discharge from the sewer plants are controlled regularly for organic matter and nutrients. Unfortunately the discharges are not in general monitored for bacteria (or vira). It is the author's experience that, e.g. secondary treatment can remove bacteria to a significant lower level, if the operational personnel have the motivation on this point.

The industrial discharges are as mentioned before under close control not only on concentration but also on the annual or monthly quantity.

10 Disfunctioning and problems

Denmark can show a large number of structural and hydraulic problems with sea outfalls. In several cases sea outfalls were set out of function and replacement were necessary. The environmental impact in those cases has been unsatisfying bathing water conditions for several months.

The explanation of this considerable number of problems can, without any doubt, be classified as bad engineering design. Most outfalls were planned at the same time in the beginning of the seventies according to the new environmental act. The design was carried out by engineers with a good experience on sewer works, but with limited knowledge on coastal structures and processes.

Since most Danish sea outfalls are ballasted plastic pipelines, the necessary ballast is essential for the stability of the outfall. In the early days several sea outfalls were designed to withstand only a 40% airfill. Due to insufficient design of the inlet structure, air intrusion was often seen. The combination of too less ballasts and air intrusion resulted in pipelines which were floating on the surface.

Another serious problem has been blocking of the diffuser. Two main reasons were found, but both of them seem to be connected with too low flow velocities in the diffuser. The first and most difficult one was due to a general overestimating of the flow, and the second was again insufficient design where necessary reduction in the cross-section area in the flow direction was neglected. The direct reason for the blockage is of course too low transport capacity for sediments and grid in the diffuser, but it should be understood that several complicated phenomena can be seen in the diffuser, like saline and sediment intrusion because of waves and/or density differences, mixing and flocculation in the diffuser pipe etc.

Direct damage due to anchors or fishing gears have taken place in several cases. The authorities who are responsible for the navigational marks have from the author's point of view in some cases been to reserved in allowing buoys to mark the diffusors.

11 Storm water overflows

Today storm water overflows seem to be the most actual and unclarified source of bathing water problems in Denmark. The meteorological situation gives around 20 overflow events in average during the summer.

The typical example is a coastal city with a well-running sewage plant and outfall. But the centre of the city has a combined sewer system including several overflows discharging either directly to the sea or to minor rivers and streams. Furthermore, the same rivers and streams often seem to be contaminated to some extend under dry weather conditions by bacteria from illegal and unknown sources. As expected the beaches near the overflows and river outlets can not live up to the bathing water standards.

Unfortunately the overflows are quite unimportant compared to ordinary sewage in the overall budgets of organic matter and nutrients. So there is no impulse for rentention and treatment for those reasons. On the other hand it is now under consideration on some locations to establish basins for bathing water reasons only in order to reduce the number of overflow events in the summer to an order of magnitude of 3 to 6. In this connection it is also under consideration to pump the content of the basins directly to the long sea outfall without treatment. But in a few cases a special outfall (a short pipeline with a big diameter and without diffusor) has been established for the storm water.

Furthwer development and research seem to be necessary on this point to clarify which strategy it will be recommended to follow in the years coming. The financial aspects of handling storm water are very heavy so well-grounded design criteria are needed.

A number of questions are still open for research. Further knowledge on the following subjects is needed:

1. Composition and decay of storm water in respect to patogens.

2. Transformation of storm water composition in streams, retention basins etc.

3. Time series of storm water flow and patogen concentration as the basis for numerical models.

4. Field investigation technique for the survey of rapid varying sewage plumes.

5. Numerical dilution models including wind, buoyancy effects, unsteady flow and stochastic behaviour of the patogens.

6. Cost benefit models for the optimum design of the system.

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When this knowledge is present, scientists and engineers with the necessary multidisciplinary background hopefully can formulate some practical design codes.

Perhaps the proportions and the complexity of this task could stimulate a common EC co-operation for the solving of this challenge. The 25 year history of Danish sea outfalls tells that, even if some European countries perhaps feel that this problem is not the firstcoming, we know that it will show up sooner or later, when the dry weather sewage problems have been solved. Having the problem in mind now can save, not only extreme amounts, but also the frustrating process of changing strategy.

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